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Final Technical Report for NASA Ames Agreement NAG 2-161

Covering the period November 1981 to December 1991

New Techniques of fabricating lightweight glass mirrors

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This work was first proposed in 1981. It dealt with both mirror blank manufacture, and fabrication to specified shape. The original proposal dealt with a means of casting borosilicate mirrors to a surface density of about 100 kg/m^2 and with the use of a swing arm generator to grind surfaces to a close approximation to a paraboloid shape.

The current mirror blanks being made at the mirror lab are direct descendants of those proposed in this grant. It was found that the method of weighing cores proposed here gave an objectionable thermal capacity that would have slowed down equilibration and annealing of large mirrors. To replace it a scheme was developed that used silicon carbide nuts and bolts to hold cores against buoyancy forces.

Large mirror blanks are currently being cast at a mean surface density of 242 kg/m^2 and with specific gravity of 0.35, and as finished are slightly less than this. This means that they are light-weighted by a factor of between 6 and 7. This is the limit of the development of that technique, at least for ground based telescopes. Mirrors of a lesser rigidity and lower surface density could be made by this technique, but to reach the original goal, the face-plates would need to be made substantially thinner too, and from our experience this would make polishing very difficult.

In 1985 a different technique was proposed to make more light-weighted blanks, by fusing tubes under pressure. This technique reached a surface density of 55 kg/m^2. This technique has now been picked up by a commercial manufacturer, and is generally available. Because this produces blanks with a more even support of the face-plate, it is possible to plan to polish thinner face-plates in this material. However, for large sizes the blanks would be overly flexible for use on the ground, and so interest in the material has been more concentrated on its use for telescope secondaries.

Generation and fabrication of surfaces have been tried both with a swing arm generator as proposed for this grant and by using a large (8m) grinding machine. Although the swing arm generator did work, the use of the large grinder was found to be simple and adequate, and it is more versatile in that a wider variety of shapes can be manufactured.

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Indeed, the molds for making a 10m. sub-mm-wave telescope were made by the grinder, and the have been successfully used to make carbon fiber telescope panels that exceed specification.

In the manufacture of mirrors with very fast focal ratios and associated unprecedented surface quality, means of rapidly and precisely testing surfaces has become a critical item. Currently the best technique found starts by grinding a surface to a close approximation to the correct figure using the large grinder. The surface is then fine ground using a stressed lap to the precision permitted by CO_2 laser testing. Then the stressed lap is used to polish the mirror. A critical part of this process is the real time control of the polishing pressure. As work proceeds, the lap is made smaller and smaller to deal with spatially smaller and smaller zones where the figure is in error. Finally the last stages of dealing with the smallest zones are polished manually.

The correctors used must have very precise surfaces, because the mirror surface is referred to theirs. An Offner corrector of this type was developed under the grant and used for polishing a 1.8m F/1 primary to a precision of 17.8 nm rms, with over 70% of the energy being focussed into a circle of 0.2" diameter. A 3.5m F/1.5 mirror has also been completed and has a surface precision of 20nm. Two ways of checking the figure inferred from an Offner corrector have been tried. One test uses a diamond turned aspheric plate. It was found that the plate had too rough a surface to allow it to be used properly. The second method uses a pentaprism, and this appears to be working satisfactorily.

A bibliography is attached that reflects both work done under this grant, and related work supported by other organizations. During the period, additional support has been obtained under NASA grant NAGW-121 as well as from the University of Arizona, National Optical Astronomy Observatories, the National Science Foundation and the U.S. Airforce. The set of articles gives both a broad overview of the techniques developed at Steward Observatory during the period of this grant, and also a detailed report.

December 1991

J.R.P. Angel..............

N.J. Woolf..............

PUBLICATIONS RELATED TO NAG2-161

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2. Generator of Off-Axis Aspherics (J. R. P. Angel, R. E. Parks). ibid., p. 316.

3. New Techniques for Fusion Bonding and Replication for Large Glass Reflectors (J. R. P. Angel)
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4. Steps Toward 8m Honeycomb Mirror Blanks. I. Rationale and Approach (J. R. P. Angel and N. J. Woolf).
Proc. of XI Texas Symposium on Relativistic Astrophysics, D. Evans, ed., *Annals N.Y.Acad.Sci.,* **422**, 163, 1983.

5. Steps Toward 8m Honeycomb Mirror Blanks. II. Experiments with Waffleplate Honeycomb Casting (J. M. Hill and J. R. P. Angel). ibid., p. 100, 1983.

6. Steps Toward 8m Honeycomb Mirror Blanks III. 1.8m Honeycomb Sandwich Blanks Cast from Borosiliate Glass (J. R. P. Angel and J. M. Hill)
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7. Steps Toward 8m Honeycomb Mirrors IV. Some Aspects of Design and Fabrication (J. R. P. Angel, N. J. Woolf, J. M. Hill and L. Goble)
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9. Steps Toward 8m Honeycomb Mirrors V. A Method for Polishing Aspheres as Fast as f/1 (J. R. P. Angel) ibid., p. 11, 1984.

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16. Large Mirrors (J. R. P. Angel) in *Modern Instrumentation and Its Influence on Astronomy,* ed. J. V. Wall, RGO, in press, 1987.

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19. A Method for Phase Shifting Interferometry in the Presence of Vibration (J. R. P. Angel and P. Wizinowich) ibid, p. 561, 1988.

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23. Recent Progress on the Columbus Project and the Mirror Laboratory Program (J. R. P. Angel, J. M. Hill, H. M. Martin and P. A. Strittmater)
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26. Progress Toward Making Lightweight 8m Mirrors of Short Focal Length (J. R. P. Angel, W. B. Davison, J. M. Hill, E. J. Mannery, and H. M. Martin) *Proc. SPIE*, **1236**, 636, 1990.

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